FRICTION AND WEAR RESISTANT COATING FOR TITANIUM AND ITS ALLOYS

FIELD OF THE INVENTION

The present invention relates to the application of an epoxide polymer as a friction and wear-resistant coating for titanium and its alloys to be employed under boundary lubrication conditions.

BACKGROUND OF THE INVENTION

Titanium and its alloys are widely used in the aerospace and machinery industries, as well as in biomedical prosthesis devices due to its high strength, light weight, high modulus and corrosion resistance. However, application of titanium and its alloys in tribological applications under load such as bearings and bushings is impeded by the high friction coefficient of titanium and its alloys which may result in the apparatus seizing up. Compared to iron, the intrinsically low yield strength of titanium makes it difficult to lubricate with conventional lubricant chemistry. The relatively weak titanium-to-titanium bond is responsible for its relatively low hardness and low yield strength. For example, the enthalpy of sublimation, which is an approximation of the titanium-to-titanium bond energy is 78.94 kJ/Mol, compared with 103.87 kJ/Mol for iron, for example.

For titanium, the hardness, Young's Modulus and tensile strength are 60 DPN (diamond pyramid number), 1.16×10^{11} N/m^2 and 20 N/mm^2, respectively, while those for iron are 150 DPN, 2×10^{11} N/m^2 and 540 N/mm^2, respectively. In addition, most of the conventional anti-wear additives such as phosphorous compounds may be corrosive to titanium and its alloys because of the high oxidation potential of titanium. Further, theoretical calculations have shown that metals with low tensile and shear strengths can exhibit high friction coefficients and high rates of material transfer to non-metallic surfaces, leading to severe adhesive wear.

Halogenated hydrocarbons have been shown to be somewhat effective in the lubrication of titanium and its alloys. Further, chlorinated compounds were identified for the lubrication of titanium but the effectiveness of these compounds was marginal and the lubrication mechanism was not understood. Iodomethane was also suggested as a lubricant for titanium and showed a friction coefficient of 0.16 for titanium sliding on itself. A titanium halide surface layer may be responsible for the reduction of the friction coefficient since titanium iodide, generated by exposure of titanium to iodine, has been demonstrated to reduce the friction coefficient from 1.2 to 0.3, which coefficient remains unchanged up to a temperature of about 400° C. More recently, it was discovered that conjugated, perchlorinated hydrocarbons such as hexachloro-1,3-butadiene can reduce the friction coefficient of titanium sliding on Ti—6Al—4V down to as low as 0.1. Further, the addition of a lubricant such as polyperfluoroalkylether (PFPE) or kerosene oil, reduces the coefficient of friction and wear damage somewhat, compared with unlubricated conditions, although reaction of titanium surfaces with these lubricants, generally under high temperature conditions, can reduce lubricant performance. Furthermore, the dense titanium oxide layer which is simultaneously formed when a fresh titanium surface is exposed to air or moisture and to which the anti-corrosive capability of titanium is attributed, can be easily sheared off or transferred under tribological conditions, leading to severe corrosive wear and adhesive wear.

A simple thermal surface treatment of titanium fails to overcome its deficiencies under tribological conditions. For

example, alpha-phase, the stable crystallographic form of commercially pure titanium below 883° C., cannot be surface-hardened by heat treatment. This is also true for alpha-alloys of titanium. The only treatment which has met with some success is annealing or recrystallizing the hexagonal close-packed crystal structure to eliminate residual stress caused by work-hardening.

Another potential solution to the lubrication and protection of titanium when used under tribological conditions would be the application of a wear-resistant organic or inorganic surface coating followed by a thermochemical surface treatment. Such thermochemical surface treatments include nitrating, carburizing, boriding, etc. However, these treatments also suffer from many technical difficulties often requiring a special apparatus with a high energy power source such as plasma, laser beam or ionic beam generators and such treatments often require a toxic atmosphere and high temperatures of up to 900° C. For these reasons, prior art surface coatings and thermochemical surface treatments are considered impractical for protecting the surface of titanium and its alloys for tribological applications.

Some examples of such coatings and thermochemical treatments can be found in U.S. Pat. Nos. 5,281,484 and 5,320,686. The first of these patents relates to titanium aluminide objects with a coating of a nickel-based alloy soldered under a vacuum. Such coatings are said to be wear resistant, oxidation resistant and to adhere well to the substrate. The second patent discloses the treatment of the surface of titanium or titanium alloys to provide a hard and wear resistant nitride layer with good adhesion. The nitride layer is formed by treating the titanium surface in an atmosphere of pure nitrogen gas at a temperature of 650°–1000° C. and a reduced pressure. This coating is also said to improve the friction and corrosion properties of titanium and its alloys.

Although epoxy polymers have been extensively used for coatings of metallic materials, they are infrequently employed for titanium-containing materials. One example of a coating of Ti—6Al—4V is given in the following series of articles:

a. Filbey, J. A. and Wightman, J. P., *Factors Affecting the Durability of Ti—6Al—4V/Epoxy Bonds,* J. Adhesion, 1989, 28, 1.

b. Filbey, J. A. and Wightman, J. P., *Factors Affecting the Durability of Ti—6Al—4V/Epoxy Bonds,* J. Adhesion, 1989, 28, 23.

c. Filbey, J. A. and Whiteman, J. P., *Factors Affecting the Durability of Ti—6Al—4V/Epoxy Bonds,* Adhesion (London), 1988, 12, 17.

d. Filbey, J. A. and Whiteman, J. P., *Factors Affecting the Durability of Ti—6Al—4V/Epoxy Bonds,* Adhes. Sci. Rev., 1, Proc. Annu. Program Rev./Workshop, 5th 1987, 1. Brinson, H. F.; Wightman, J. P.; Ward, T. C. Ed..

e. Roche, A.; Gaillard, F.; Romand, M.; Von Fahnestock, M., *Metal-Adhesive Bonded Systems: Adhesion Measurement Using a Three-Point Flexure Test,* J. Adhes. Sci. Technol. 1987, 1 (2), 145.

These articles report the influence of different surface pretreatment methods, including the use of a thick organic titanate layer as primer, on the durability of the titanium alloy/epoxy bonds in a three-point flexure test.

As wear-resistant fillers for epoxy coatings in general, several different materials have been employed. For example, a corundum, ceramic wool, ceramic spheres, zinc oxide, bauxite, silica sand, titanium dioxide and other materials have been employed. Further, loadings of high concentrations of diamond powder, from 30 to 85%, have been